The Importance of Particle Size Distribution when Defining 80% TSS Removal Efficiency

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? | *or……80% removal of what?*

A target TSS removal goal of <u>80%</u> is only part of the equation. Let's explore why influent sediment <u>*particle size*</u> should also be factored into stormwater quality design guidelines.

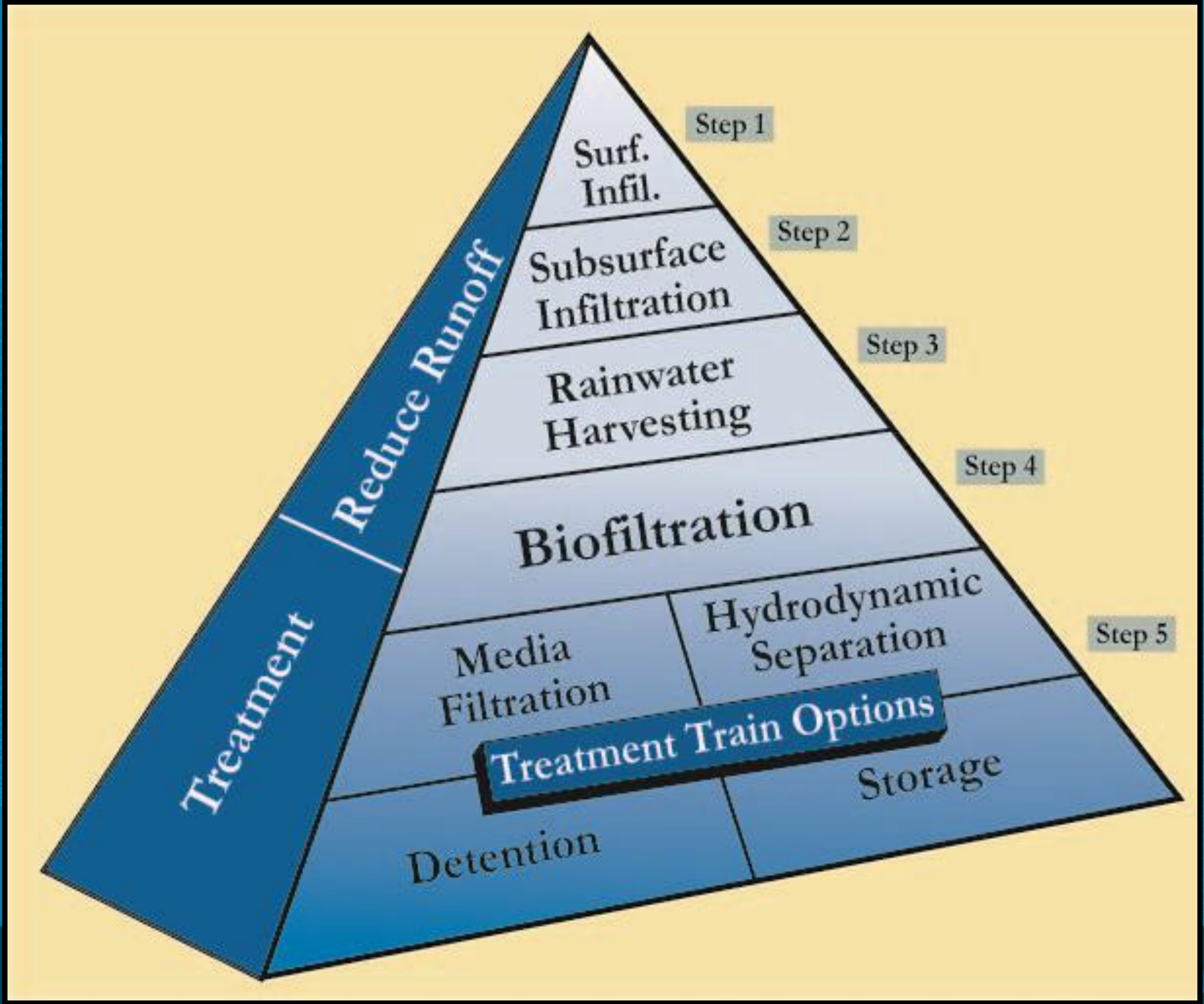
Land-based (public domain) BMPs
vs.
Manufactured Treatment Devices (MTDs)

- Land-based BMPs commonly assigned a TSS removal efficiency based on "presumptive performance" capabilities irrespective of influent particle size distribution (PSD).

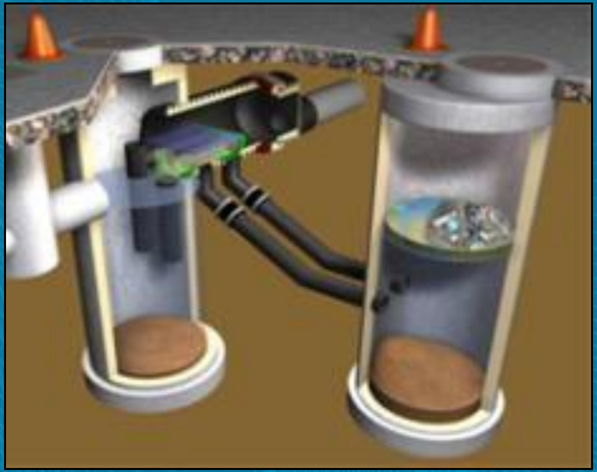
- MTD approvals based on lab/field testing results that rely on a PSD. And, evaluating those tests can be a challenge.

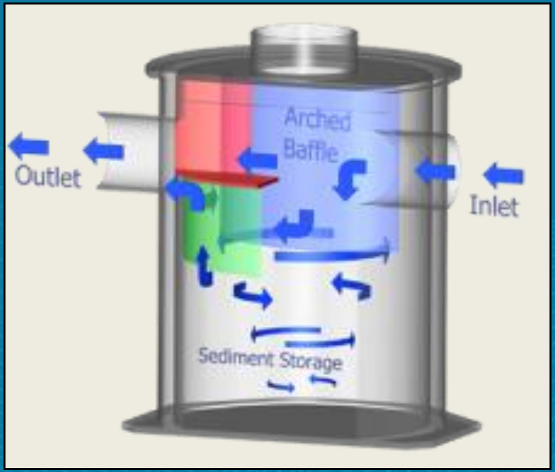
- Let's look at Hydrodynamic Separators (HDS) lab testing to show significance of PSD for sizing and facility design.

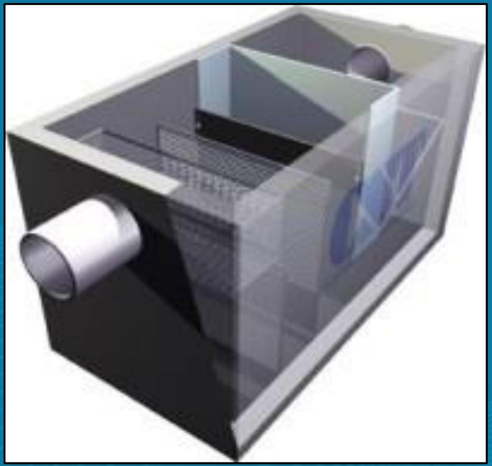
Low Impact Development (LID) Technology Selection Pyramid

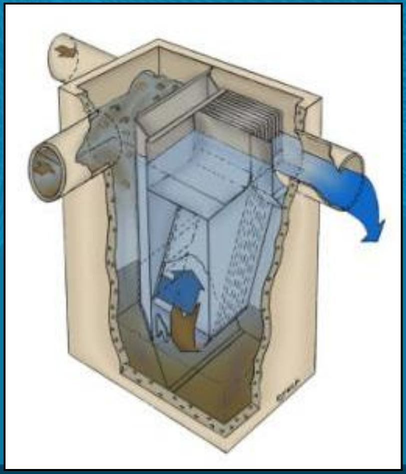


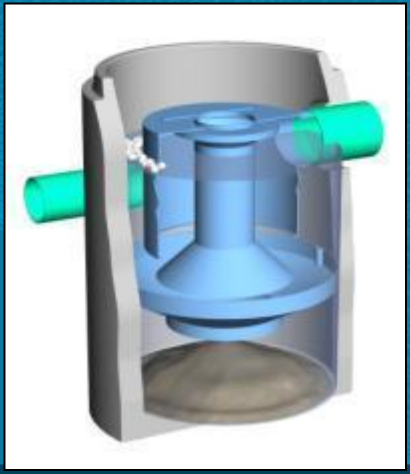
Hydrodynamic Separators (HDSs) as an example of the role of particle size









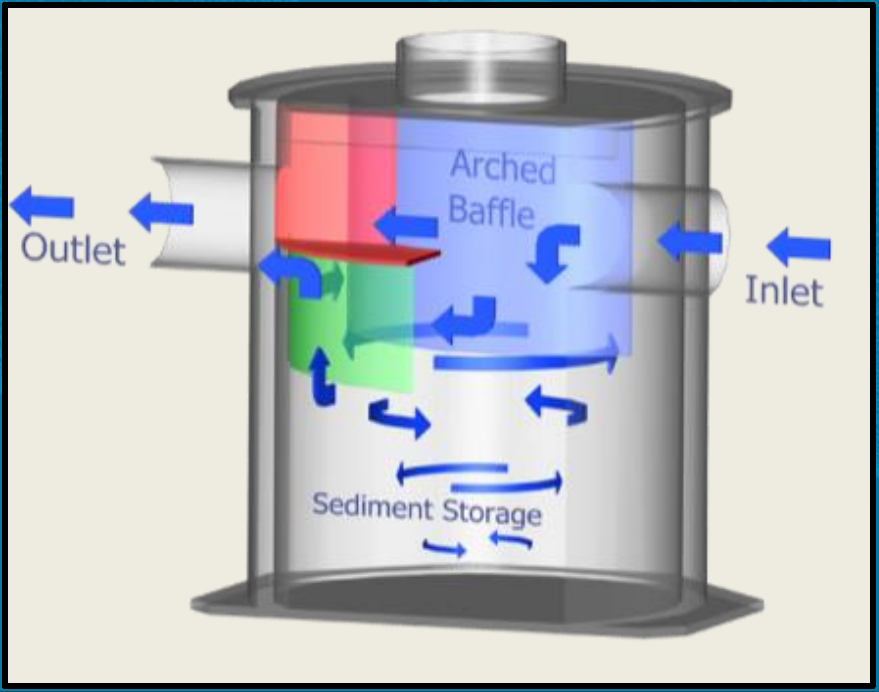


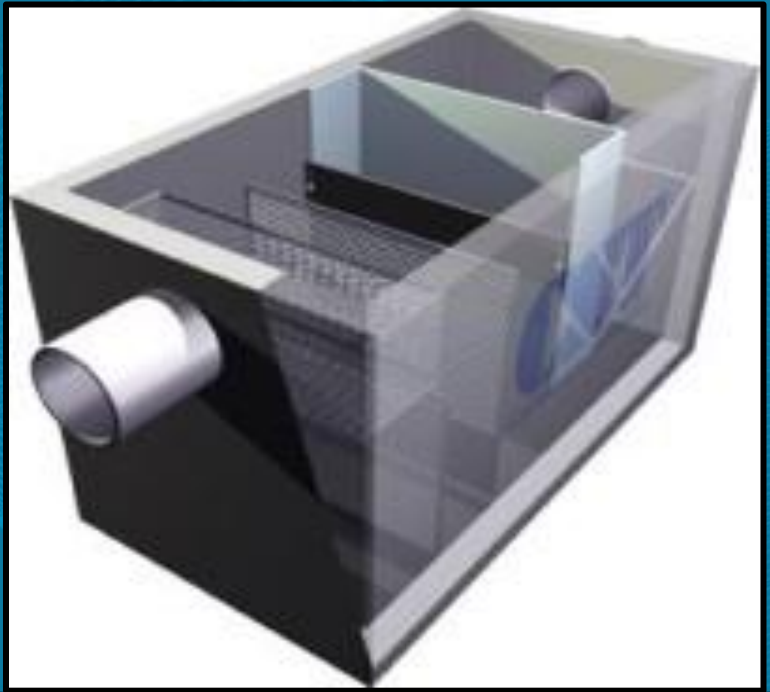
Types of HDSs

Captures sediment, debris, floatables, oil

Vortex type =
Gravitational & Centrifugal Forces

Vault type =
Gravitational Forces





Where I got the idea to use Peclet Number

UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

PROJECT REPORT NO. 494

Performance Assessment of Underground Stormwater Treatment Devices

By

Matthew A. Wilson, John S. Gulliver, Omid Mohseni, and Ray M. Hozalski

Prepared for
Local Road Research Board
and
Twin Cities Metropolitan Council

July 2007
Minneapolis, Minnesota

What is the Peclet Number?

- Provides a simple means to predict HDS performance using a different particle size
- Allows for HDS sizing charts for annual or per storm event TSS removal efficiency
- Performance curves from different HDSs having different PSDs can be compared.

Peclet Number (Pe)

$$Pe = (d \cdot h \cdot Vs) / Q$$

d = Horizontal flow dimension in feet
h = Vertical flow dimension in feet
Vs = Particle settling velocity in feet/sec
Q = Flow rate in cubic feet/second

- "d" in Vortex HDS = diameter of effective treatment area
- "d" in Vault HDS = long axis of effective treatment area (parallel to flow)

Two Key Considerations

(and probably some more)

1. Calculations based on median (d50) particle size, not full PSD

2. Performance curve profile does not change for different d50 simulations

Let's Assume I'm Right
it'll save time

Steps for Predictive Performance Method

1. Calculate Peclet Number using lab test data
2. Solve for flow rate (Q)
3. Convert Q to surface area loading rate (gpm/ft^2)
4. Make table for RE% vs. Loading Rate
5. Plot performance curve for selected particles size
6. Make sizing chart(s) for:
   a) per storm TSS removal, or
   b) annual TSS removal

Calculate Pe for Tested HDS

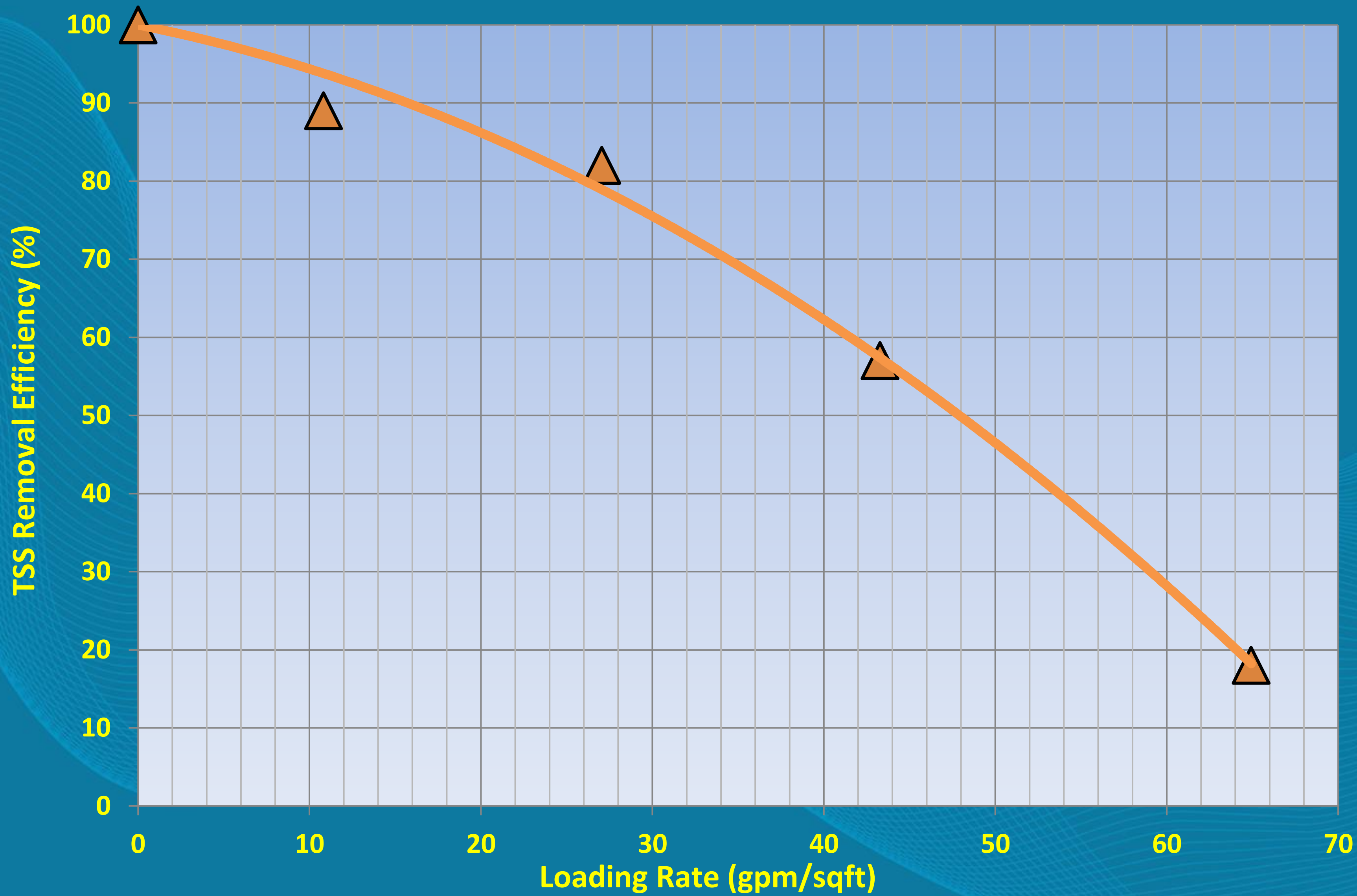
Test Parameters	Q (cfs)	Loading Rate (gpm/ft²)	TSS RE (%)	Pe (unitless)
d_{50} = 110 µm (OK-110)	0	0	100	NA
Vs = 0.021 ft/s	0.20	10.8	89	1.33
SG = 2.65	0.50	27.1	82	0.53
d = 3.3 ft	0.80	43.3	57	0.33
h = 3.83 ft	1.20	64.9	18	0.22

Pe = (d · h · Vs) / Q

Example: Q = 0.2 cfs

Pe = (3.3 ft · 3.83 ft · 0.021 ft/sec) / 0.2 cfs = 1.33

HDS Performance Curve



Calculate Particle Settling Velocity (Vs)

Term	Variable	Units	Description
Gs	2.65		Specific gravity of particle
ρ_s	165.07	lb/ft^3	Density of particle
ρ_w	62.29	lb/ft^3	Density of water
g	32.20	ft/s^2	Acceleration due to gravity
T	20.00	C°	Temperature of water
T	68	F°	Temperature of water
μ	2.09E-05	$lb*s/ft^2$	Dynamic viscosity of water at given temp.
υ	1.08E-05	ft^2/s	Kinematic Viscosity of water
D	110	micron	Diameter of particle
Vs	0.024	ft/s	Settling velocity, Cheng Formula
Vs	0.02080	ft/s	Settling velocity, Stoke's Law
Vs	0.029	ft/s	Settling velocity, Ferguson & Church

Input Value

Stoke’s Law Particle Settling Velocities

Particle Size (µm)	Vs (ft/sec)
45	0.0085
50	0.010
67	0.013
75	0.014
90	0.017
110	0.021
125	0.024

Performance Summary - 45 µm

Rearrange equation to solve for Q

$Q = (3.3\ ft \cdot 3.83\ ft \cdot Vs) / Pe$

RE and Pe constant

Parameters	Q (cfs)	Loading Rate (gpm/ft²)	RE (%)	Pe (unitless)
d_{50} = 45 µm	0	0	100	NA
Vs = 0.0085 ft/sec	0.081	4.4	89	1.33
SG = 2.65	0.202	10.9	82	0.53
d = 3.3 ft (8.3 ft²)	0.325	17.5	57	0.33
h = 3.83 ft	0.486	26.3	18	0.22

Loading Rate = Q cfs · 448.83 gpm/cfs / Area ft²

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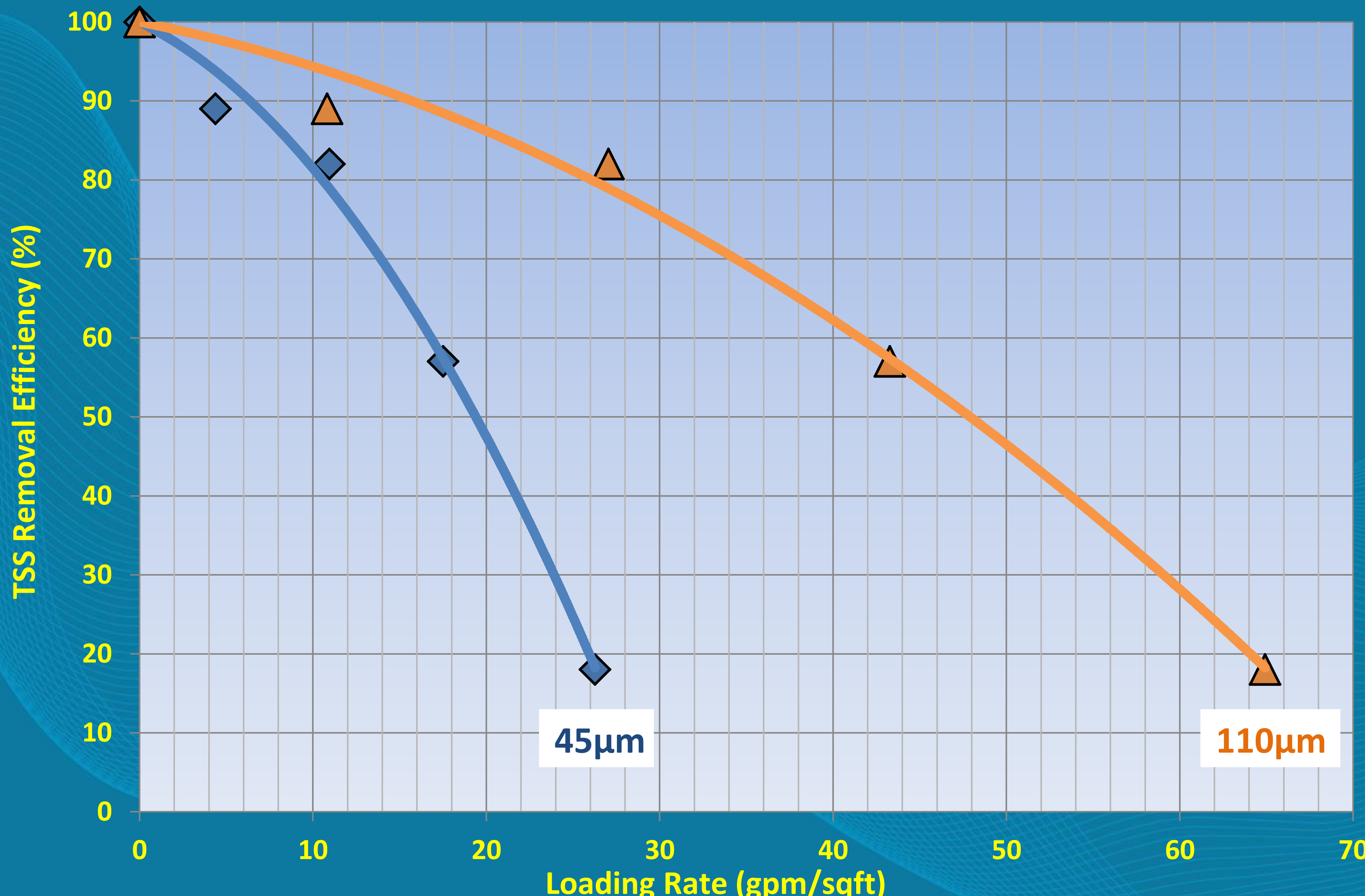
HDS Performance Curves for 45 and 110 µm



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50 µm				
Parameters	**Q (cfs)**	**Loading Rate (gpm/ft²)**	**RE (%)**	**Pe (unitless)**
d_{50} = 50 µm	0	0	100	NA
Vs = 0.010 ft/sec	0.10	5.2	89	1.33
SG = 2.65	0.24	12.9	82	0.53
d = 3.3 ft	0.38	20.6	57	0.33
h = 3.83 ft	0.57	30.9	18	0.22

67 µm (Old d_{50} from NJDEP PSD)				
Parameters	**Q (cfs)**	**Loading Rate (gpm/ft²)**	**RE (%)**	**Pe (unitless)**
d_{50} = 67 µm	0	0	100	NA
Vs = 0.0.013 ft/sec	0.124	6.7	89	1.33
SG = 2.65	0.310	16.7	82	0.53
d = 3.3 ft	0.495	26.8	57	0.33
h = 3.83 ft	0.743	40.2	18	0.22

75 µm				
Parameters	**Q (cfs)**	**Loading Rate (gpm/ft^2)**	**RE (%)**	**Pe (unitless)**
d_{50} = 75 µm	0	0	100	NA
Vs = 0.014 ft/sec	0.133	7.2	89	1.33
SG = 2.65	0.333	18.0	82	0.53
d = 3.3 ft	0.533	28.9	57	0.33
h = 3.83 ft	0.800	43.3	18	0.22

90 µm				
Parameters	**Q (cfs)**	**Loading Rate (gpm/ft^2)**	**RE (%)**	**Pe (unitless)**
d_{50} = 90 µm	0	0	100	NA
Vs = 0.017 ft/sec	0.162	8.8	89	1.33
SG = 2.65	0.405	21.9	82	0.53
d = 3.3 ft	0.648	35.0	57	0.33
h = 3.83 ft	0.971	52.6	18	0.22

110 µm				
Parameters	Q (cfs)	Loading Rate (gpm/ft^2)	RE (%)	Pe (unitless)
d_{50} = 110 µm	0	0	100	NA
Vs = 0.021 ft/sec	0.2	10.8	89	1.33
SG = 2.65	0.5	27.1	82	0.53
d = 3.3 ft	0.8	43.3	57	0.33
h = 3.83 ft	1.2	64.9	18	0.22

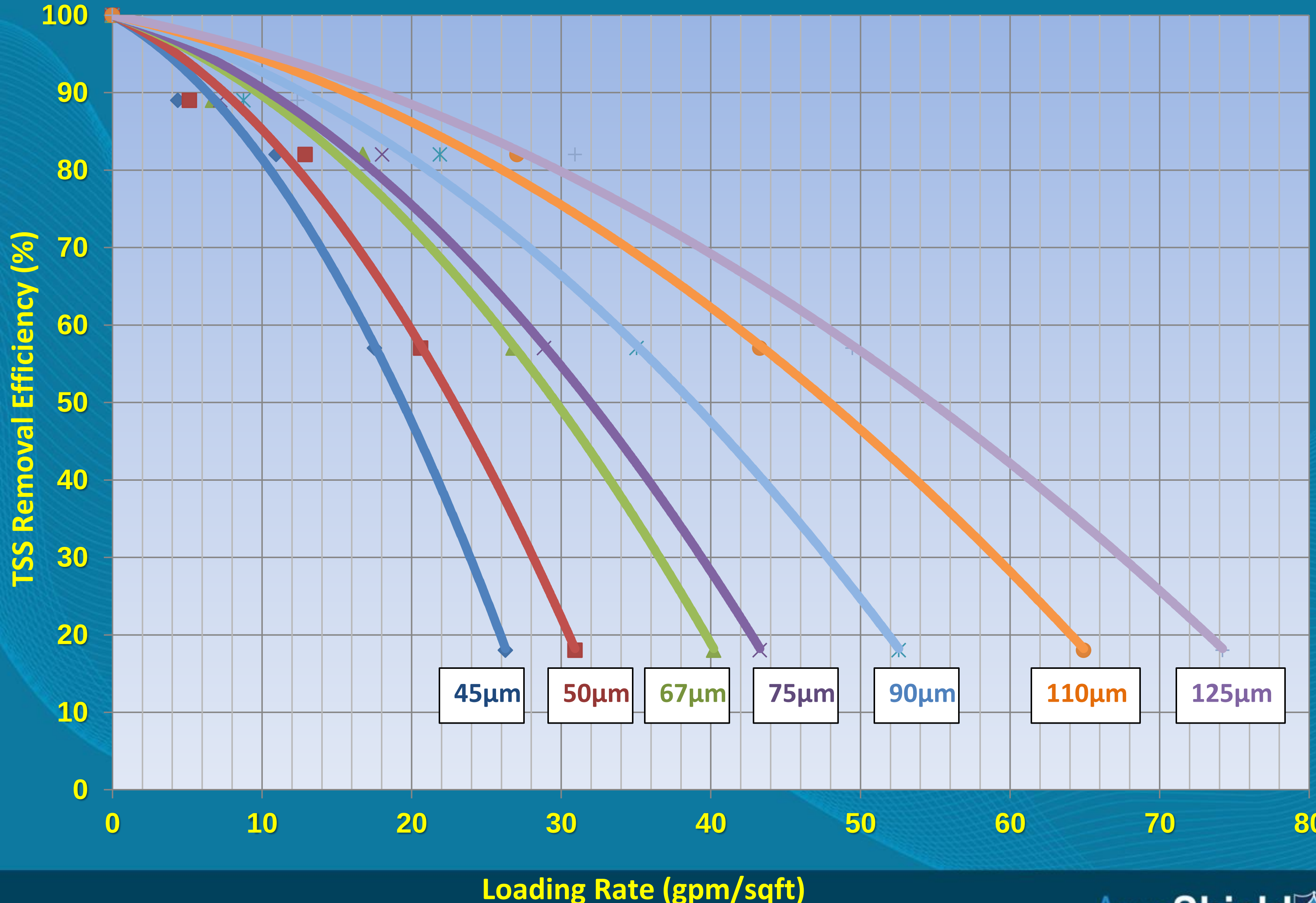
125 µm				
Parameters	Q (cfs)	Loading Rate (gpm/ft^2)	RE (%)	Pe (unitless)
d_{50} = 125 µm	0	0	100	NA
Vs = 0.024 ft/sec	0.229	12.4	89	1.33
SG = 2.65	0.571	30.9	82	0.53
d = 3.3 ft	0.914	49.5	57	0.33
h = 3.83 ft	1.371	74.2	18	0.22

HDS Performance Summary

45 µm		50 µm		67 µm		75 µm		90 µm		110 µm		125 µm	
RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2	RE (%)	LR gpm/ft^2
89	4.4	89	5.2	89	6.7	89	7.2	89	8.8	89	10.8	89	12.4
82	10.9	82	12.9	82	16.7	82	18.0	82	21.9	82	27.1	82	30.9
57	17.5	57	20.6	57	26.8	57	28.9	57	35.0	57	43.3	57	49.5
18	26.3	18	30.9	18	40.2	18	43.3	18	52.6	18	64.9	18	74.2

Note: Removal efficiencies are constant for each particle size

HDS Performance Curves for Different Particle Sizes



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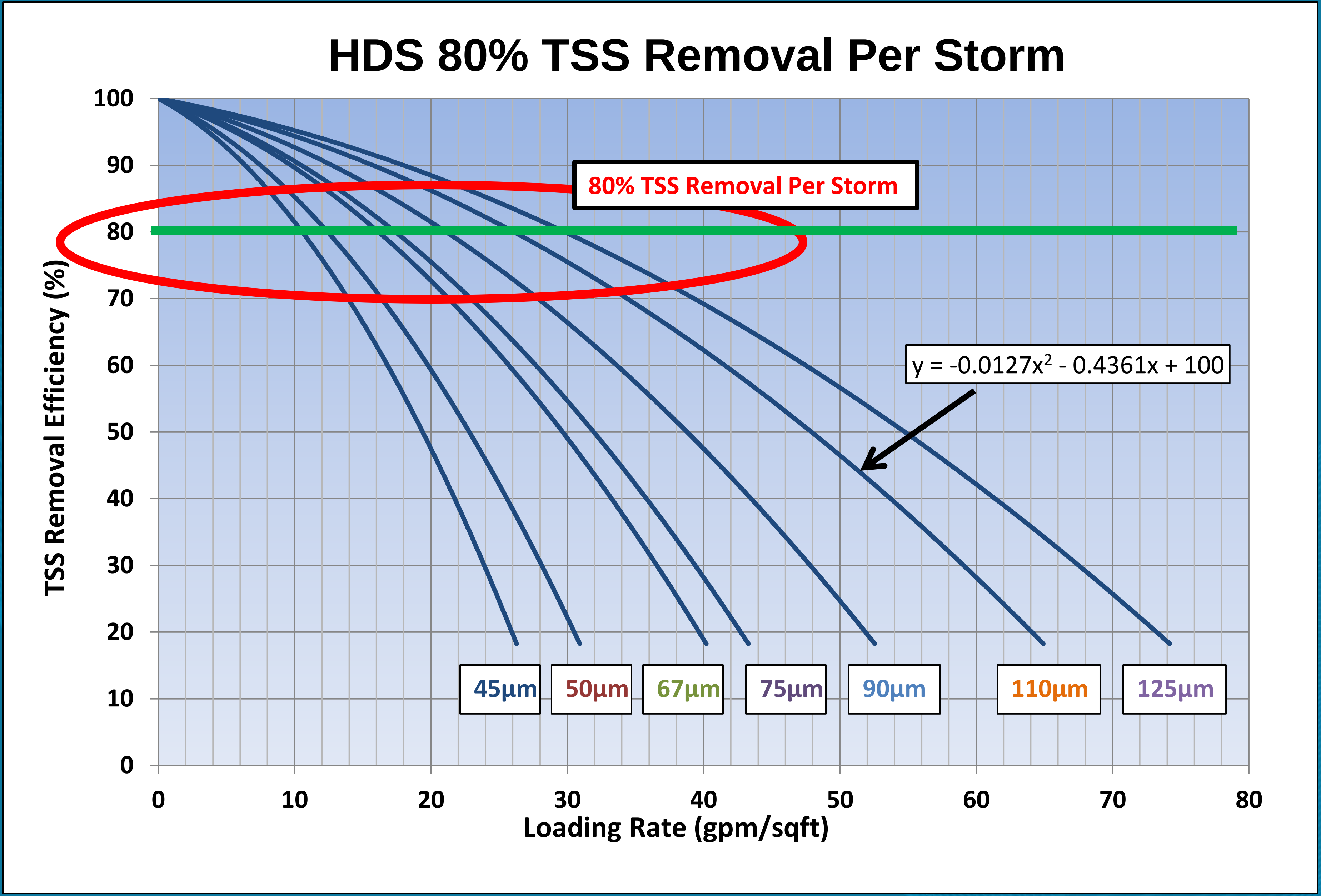

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HDS #1 Sizing Charts: 80% TSS Removal ***per Storm***

Example HDS Model Diameter (ft)	Effective Treatment Area (ft^2)	Particle Size and Loading Rate						
		45 µm	50 µm	67 µm	75 µm	90 µm	110 µm	125 µm
		10.5 gpm/ft^2	12.2 gpm/ft^2	16.0 gpm/ft^2	17.5 gpm/ft^2	21.0 gpm/ft^2	26.0 gpm/ft^2	30.0 gpm/ft^2
		WQTF (cfs)	WQTF (cfs)	WQTF (cfs)	WQTF (cfs)	WQTF (cfs)	WQTF (cfs)	WQTF (cfs)
4.0	12.6	0.29	0.34	0.45	0.49	0.59	0.73	0.84
5.0	19.6	0.46	0.53	0.70	0.76	0.92	1.14	1.31
6.0	28.3	0.66	0.77	1.01	1.10	1.32	1.64	1.89
8.0	50.3	1.18	1.37	1.79	1.96	2.35	2.91	3.36
10.0	78.5	1.84	2.13	2.80	3.06	3.67	4.54	5.24

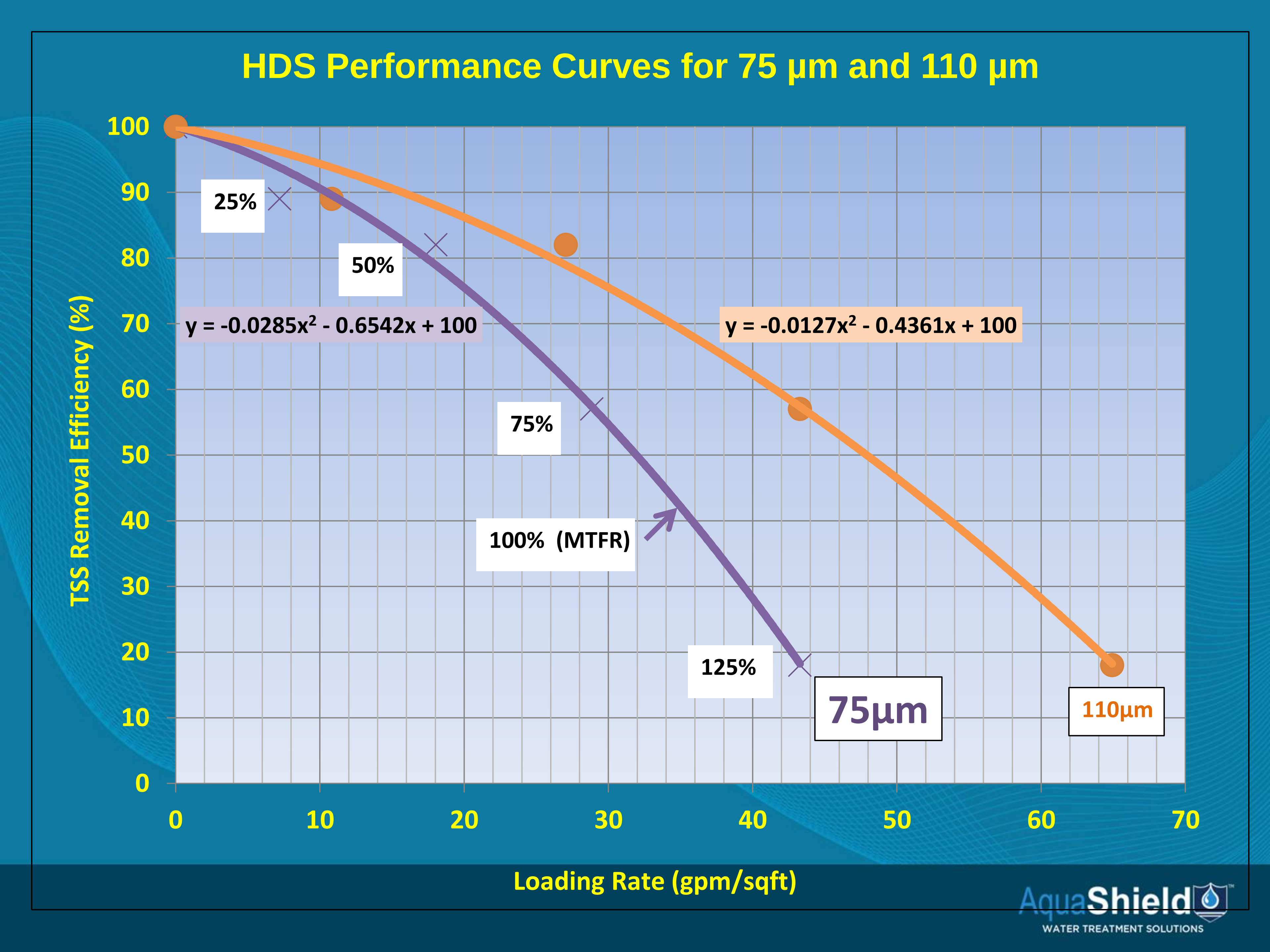
Water Quality Treatment Flow = (Area · Loading Rate) / 448.83 gpm/cfs

80% Annual TSS Removal @ Chattanooga

Sizing by Weight Factor Method

19.7 years of rainfall within 55 year span, Lovell Field Airport (from National Climatic Data Center)

Storm Intensity (in/hr)	Incremental Rainfall (%)	Rainfall by Weighting (%)	Weight Factor (%)
0.08-0.10	27.45	57.15	**57**
0.10-0.12	11.99		
0.12-0.14	9.87		
0.14-0.16	7.84		
0.16-0.18	6.53	21.48	**22**
0.18-0.20	5.20		
0.20-0.25	9.75		
0.25-0.35	9.79	17.21	**17**
0.35-0.45	4.74		
0.45-0.55	2.68		
0.55-0.65	1.53	3.08	**3**
0.65-0.75	0.99		
0.75-1.00	0.86		
1.00-1.25	0.45	0.78	**1**
1.25-1.50	0.22		
1.50-2.00	0.11		
Total	100	100	100



HDS Performance Curves for 75 µm and 110 µm
TSS Removal Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Loading Rate (gpm/sqft)
25%
50%
75%
100% (MTFR)
125%
y = -0.0285x² - 0.6542x + 100
y = -0.0127x² - 0.4361x + 100
75µm
110µm
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Annual TSS Removal for 75 Micron Particle Size

% Operating Rate	Loading Rate (gpm/ft^2)*	TSS Removal (%)	Chattanooga Weight Factor	Chattanooga Weighted TSS Removal (%)
25	7.2	89	0.57	50.73
50	18.0	82	0.22	18.04
75	28.9	57	0.17	9.69
100 [MTFR]	34.6	42	0.03	1.26
125	43.3	18	0.01	0.18
	** From Pe calcs 75µm*	Net Annual Removal		79.9 [80]

MTFR = Maximum Treatment Flow Rate

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Example HDS Sizing Chart
80% Annual TSS Removal for 75 µm [MTFR = 34.6 gpm/ft^2)

HDS Model Diameter (ft)	Treatment Area (ft^2)	Water Quality Treatment Flow (cfs)
4.0	12.6	0.97
5.0	19.6	1.51
6.0	28.3	2.18
8.0	50.3	3.88
10.0	78.5	6.05

WQTF (cfs) = (Treatment Area · Loading Rate) / gpm/cfs
WQTF (cfs) = (X.X ft^2 · 34.6 gpm/ft^2) / 448.83 gpm/cfs

Example HDS Sizing Chart
80% Annual TSS Removal for 110 µm [MTFR = 52 gpm/ft^2)

HDS Model Diameter (ft)	Treatment Area (ft^2)	Water Quality Treatment Flow (cfs)
4.0	12.6	1.46
5.0	19.6	2.27
6.0	28.3	3.28
8.0	50.3	5.83
10.0	78.5	9.09

WQTF (cfs) = (Treatment Area · Loading Rate) / gpm/cfs
WQTF (cfs) = (X.X ft^2 · 52 gpm/ft^2) / 448.83 gpm/cfs

Comparison of 75 µm & 110 µm HDS Sizing Charts

HDS Model Diameter (ft)	WQTF 75 µm (cfs)	WQTF 110 µm (cfs)
4.0	0.97	1.46
5.0	1.51	2.27
6.0	2.18	3.28
8.0	3.88	5.83
10.0	6.05	9.09

Example Q = 3.0 cfs

- 75 µm @ HDS Model 8.0
- 110 µm @ HDS Model 6.0

Comparison of 75 µm & 110 µm HDS Sizing Charts
Annual vs. Per Storm

HDS Model Diameter (ft)	75 µm		110 µm	
	Annual WQTF (cfs)	Per Storm WQTF (cfs)	Annual WQTF (cfs)	Per Storm WQTF (cfs)
4.0	0.97	0.49	1.46	0.73
5.0	1.51	0.76	2.27	1.14
6.0	2.18	1.10	3.28	1.64
8.0	3.88	1.96	5.83	2.91
10.0	6.05	3.06	9.09	4.54

Consequences of PSD Specification

Undersizing

- Potential for diminished performance and increased potential for re-suspension (scour)

- Concern for runoff conveyance (tailwater backup) due to potentially undersized piping and water quality unit

- Leads to increased maintenance frequency due to decreased storage capacity and long term functionality which increase operational costs.

Consequences of PSD Specification

<u>Oversizing</u>

- Increases footprint, can be a problem for tight spaces and/or retrofits
- Increases project costs from a properly sized device
- *Conservative TSS removal efficiency*
- *Pollutant loading will ultimately dictate maintenance frequency and cost*

<u>Trash Only</u>

If PSD specification is too coarse, maximum hydraulic capacity may be exceeded causing catastrophic failure

It's all about clean water…..

Tennessee River, Chattanooga

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Thank you.

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